Biological Space Adaptation to Implant Dimensions

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Purpose: *Implant osseointegration has been well described, but coronal osseous healing continues to be investigated because of its impact on esthetic results and long-term maintenance. Although numerous implant diameters and designs exist, little is known about the role of these parameters on surrounding bone. Therefore, this study aimed at elucidating the influence of implant dimensions on crestal bone morphology.* ***Materials and Methods:*** *Sixty Biomet/3i implants (20 standard, 20 wide, and 20 expanded platform [XP]) were randomly placed in posterior quadrants of 5 mongrel dogs. After healing, exposure of the implants to the oral cavity, and euthanasia of the animals, samples were harvested. Histomorphometric measurements were performed to determine the bone cuff height, width, and angle, and analysis of variance was applied to compare groups.* ***Results:*** *Formation of a peri-implant cuff was noticed in all implant sites. Mean cuff height was 0.8 mm, 1 mm, and 1.4 mm for standard, wide, and XP implants, respectively. Mean cuff width was 1.9 mm, 2.1 mm, and 2.8 mm for standard, wide, and XP implants, respectively. These differences were statistically significant between wide and XP implants (*P = .035*), as well as between standard and XP implants (*P = .001*). Angle did not differ significantly between implants of different platform widths.* ***Conclusions:*** *Craterization after placement of healing abutments and a healing period was observed around all implants. Width and height of the cuff varied significantly with implant diameter and platform design, but the angle formed with the implant did not vary significantly.* Int J Oral Maxillofac Implants 2008;23:99–104

Key words: *animal study, bone healing, dental implants, implant diameter, osseointegration*

The long-term stability of dental implant osseointegration has been well described over the past decades.[1–3] The implant interface with the oral cavity has been under clinical[4,5] and histologic[6–8] scrutiny because preservation of this area is important for long-term maintenance of the restoration.[9,10] Furthermore, conservation of the overlying soft tissue contours is important for esthetic purposes.[11] After exposure to the oral cavity, soft tissue healing around an implant differs greatly from the attachment around a natural tooth; it is similar to a scar tissue.[12] In addition, the bony crest architecture undergoes early changes, which have been compared to the creation of a "biological width" similar to that around natural teeth.[13] The bone crest, even when at the coronal level at time of surgical placement, is expected to migrate along the implant axis shortly after uncovering[1,2] until meeting the rough surface. If the distance from the implant platform to this landmark is less than that of a biological width, a variable dimension that is, on average, approximately 2 mm, the osseous crest migrates farther until it reaches such a distance.[14,15]

The reasons for the formation of a cuff-like architecture around implants are unclear.[16] A comparison with the biological width around natural teeth is limited, since the angulated bony architecture adjacent to dental implants would be considered pathological in a natural dentition. However, little is known regarding the horizontal component of the cuff. Microgap leakage[17,18] and mechanical stress[19] have been cited as principal causes for such a reaction. In particular, it is possible that the crater size may be dependent upon the diameter of the implant head if mechanical stress is the main etiology, as has been suggested by preliminary finite element analysis studies.[20] Therefore, the purpose of this investigation was to compare osseous healing around implants with various diameters and head designs.

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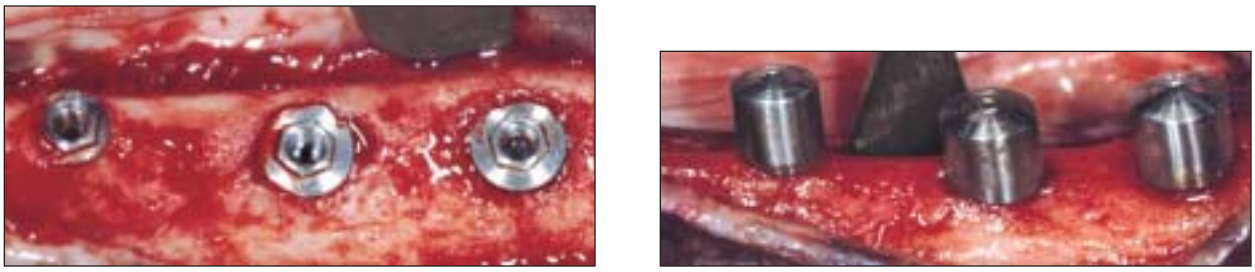


Fig 1 Surgical site at the time of implant placement, showing random positioning of the 3 implant types. *(Left)* Implants were positioned in areas of ample buccolingual bone width with sufficient distance between them to allow for histologic evaluation of adjacent and distant bone. *(Right)* At stage 2, implants were uncovered and 2-piece healing abutments were inserted.

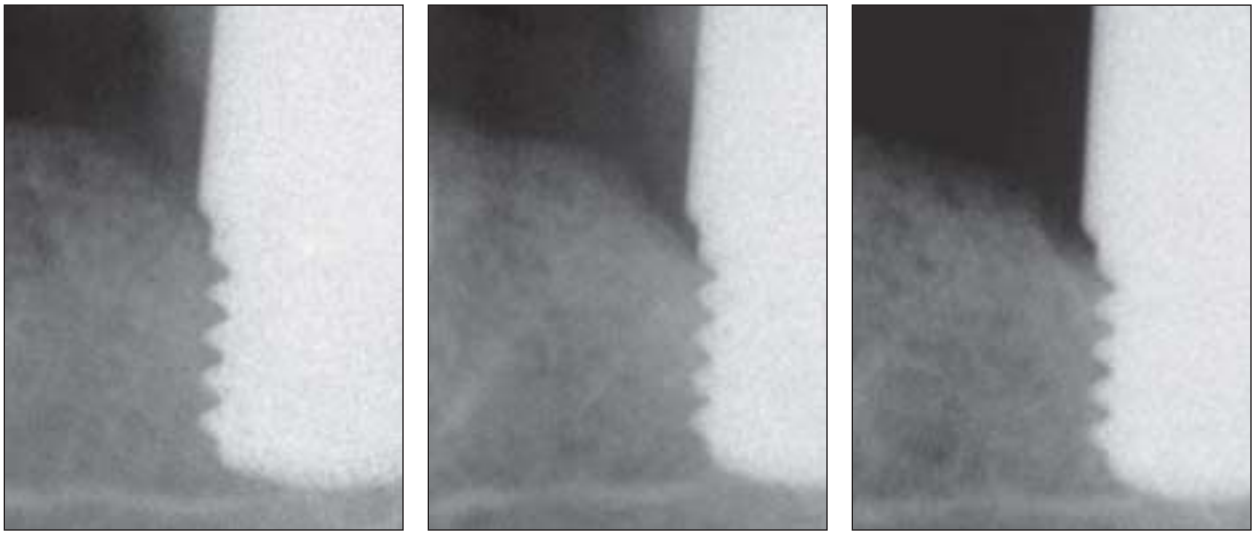


Fig 2 Radiographic follow-up of osseous cuff formation *(left)* at implant uncovering, *(center)* at 2 months, and *(right)* at 3 months.

MATERIALS AND METHODS

This prospective randomized descriptive experimental animal study compared the architecture of crestal bone around 3 Osseotite (Biomet/3i, Palm Beach Gardens, FL) implant types: standard, 3.75 mm diameter; wide, 5 mm diameter; and expanded platform (XP), 4/5 mm (Figs 1 and 2). Implants of a customized length (5 mm) were provided for the study.

Preparation of Edentulous Quadrants

General anesthesia was induced in 5 mongrel dogs via the intravenous administration of 20 mg/kg of 4% thiamylal sodium (Surital; Park Davis, Detroit, MI) and the subsequent inhalation of 1% halothane along with a 50% mixture of nitrous oxide and oxygen. The surgical sites were disinfected with povidone-iodine (Betadine; Purdue Frederick, Newport, CT) and local anesthesia was induced with 2% lidocaine HCl (1:100,000). The second, third, and fourth premolars and first molars of all 4 quadrants were extracted bilaterally as atraumatically as possible using midcoronal facial to lingual sectioning. Following odontectomy, alveoloplasty was performed on the remaining alveolar ridge for improved form and elimination of bony spicules. Surgical flaps were reapproximated and closed with 4-0 polyglactin 910 suture (Vicryl; Johnson & Johnson/Ethicon, Somerville, NJ). Following surgery, butorphanol (Torbugesic; Aveco, Fort Dodge, IA; 0.2 to 0.4 mg/kg) was administered intramuscularly every 2 to 5 hours as needed for postoperative discomfort, and a 300,000 IU/mL preparation of penicillin G benzathine and penicillin G procaine (Flo-Cillin; Fort Dodge, Fort Dodge, IA) was administered intramuscularly at a dose of 1 mL/5–10 kg to reduce potential of infection. The dogs remained on a soft diet (Science Diet; Hill's Pet Nutrition, Topeka, KS) to reduce potential trauma to the surgical sites. Extraction sites were allowed to heal for 2 months prior to the second surgery in order to imitate an intact ridge with presence of cortical bone.

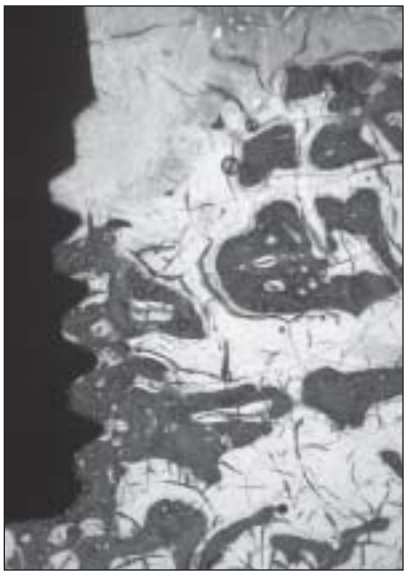


Fig 3 *(Left)* Histologic specimen of a 4.1-mm implant utilized for histomorphometric analysis and adjacent bone showing the osseous cuff.

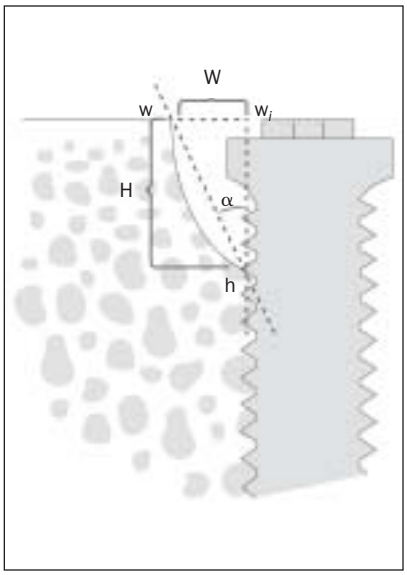


Fig 4 *(Right)* Diagram of histomorphometric landmarks and measurements. h = most coronal bone-implant contact; w = intersection of crestal and cuff bone; w_i = projection of w on implant long axis; H = distance from h to w_i; W = distance from w to w_i; α = angle formed by lines h-w_i and h-w.

Implant Placement and Uncovering

General anesthesia and local preparation were identical to the first surgery. For each quadrant, full-thickness mucoperiosteal flaps were reflected, and implant surgical sites were prepared in the standard fashion, with at least 10 mm between them. Osteotomies and implant placement were performed so that each quadrant received 1 implant of each type. The mesiodistal positions of implants were randomly generated prior to the study using software (Microsoft Excel; Microsoft, Redmond, WA). After the placement of cover screws, surgical flaps were sutured with primary closure. Recovery and postoperative care were identical to the first surgery.

After 2 months of healing, full-thickness mucoperiosteal flaps were elevated to expose the implants. Cover screws were removed, and standard healing abutments (5 mm in height and 5 mm in diameter) were placed. Surgical flaps were positioned and sutured. After healing, a hygiene regimen consisting of weekly brushing and visual examination was instituted for the remaining 3 months to minimize inflammation. Healing abutments were disconnected and immediately reconnected monthly to imitate prosthetic manipulations. Peri-implant osseous maturation was monitored using standardized radiographs (Fig 3).

Specimen Preparation

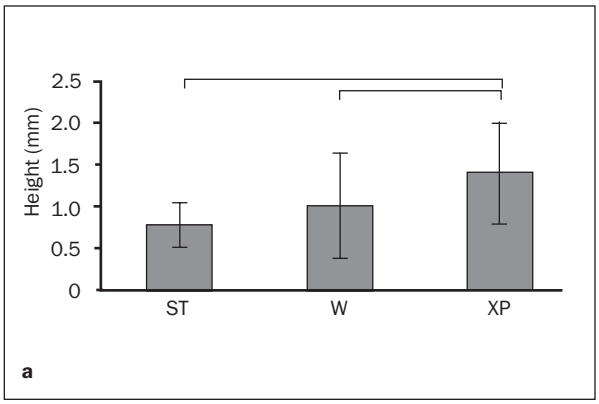
Animals were euthanized at 3 months with an overdose of sodium pentobarbital (Sleepaway; Fort Dodge). Specimens were harvested, fixed in 70% ethanol, and dehydrated with a series of graded alcohols and 2-hydroxyethyl methacrylate (GMA). Plastic infiltration of the specimens was accomplished with an even mixture of GMA and embedding medium (Technovit 7200 VLC, Kulzer:EXAKT, Kulzer & Co. Norderstedt, Germany) followed by repeated immersions in 100% embedding medium. Specimens were later sectioned with use of a microgrinding system (EXAKT Apparatebau; Norderstedt, Germany; EXAKT Medical Instruments, Oklahoma City, OK) until a final desired thickness of less than 50 μm was obtained.[21]

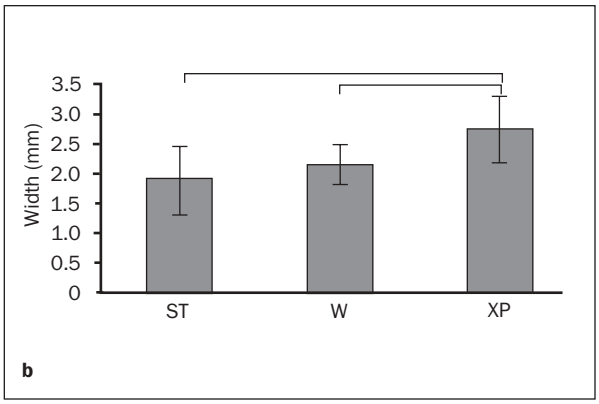
Histomorphometric Analysis

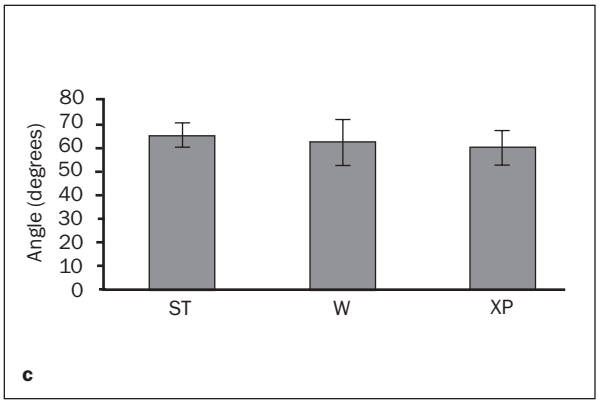
Histologic specimens were analyzed under a 100× objective using a semiautomated computerized technique with a Leitz Orthoplan microscope interfaced with an IBM computer and a Bioquant HIPAD digitizer. Histomorphometric measurements were performed using Image-Pro Plus software (Media Cybernetics, Silver Spring, MD; Fig 4). For each implant, mesial and distal cuffs were defined by detecting a point (w) where the bone met the osseous crest. The apical location of the cuff was defined as the first bone-implant contact (h). Thus, the cuff height (H) was measured by projecting w on the implant body (w_i) and measuring the distance h-w_i; whereas cuff width (W) was measured from w_i to w. The angle α formed by the angled bone against the implant was measured by tracing the lines h-w_i and h-w (Fig 4).

Statistical Analysis

Power analysis was performed using a randomized block analysis of variance (ANOVA) to reach a power of 0.8 and $\alpha = 0.05$ with a medium effect size of implant size and a small effect size of implant position. All measurements were repeated at 2 time points by the same trained examiner. Statistical comparisons were performed using ANOVA and software (SPSS 9.0; SPSS, Chicago, IL).







Figs 5a to 5c Histomorphometric results for (a) cuff height, (b) width, and (c) angle (mean ± SD). Brackets show statistically significant differences ($P < .005$) between groups. ST = standard; W = wide, XP = expanded platform.

RESULTS

Sixty implants were inserted. At stage 2, 6 implants had not become osseointegrated (1 standard, 2 wide, and 3 XPs). Four implants were lost in the mandible and 2 in the maxilla. Formation of a peri-implant cuff was observed at all implant sites.

Cuff height was not constant between implant types. For standard implants, it was 0.8 mm (± 0.27 SD), whereas it was 1 mm (± 0.64 SD) for wide implants and 1.4 mm (± 0.6 SD) for XP implants. The difference between XP and wide implants was statistically significant ($P = .035$), as was the difference between XP and standard implants ($P = .001$; Fig 5a).

For cuff width, a similar pattern was observed. Cuff width was 1.9 mm (± 0.56 SD) for standard implants, 2.1 mm (± 0.33 SD) for the wide implants, and 2.8 mm (± 0.56 SD) for XP implants. There were statistically significant differences between XP and wide implants ($P < .001$) and between XP and standard implants ($P < .001$; Fig 5b).

Finally, the angle between the implant and the cuff was similar between implant types. It measured 64 degrees (± 5 SD) for standard implants, 62 degrees (±10 SD) for wide implants, and 59 degrees (±7 SD) for XP implants. These differences were not statistically significant (Fig 5c).

DISCUSSION

A stable osseous contour around dental implants is crucial to maintenance and esthetic purposes, yet bone remodeling is not well understood. This study was undertaken to identify any association between implant dimensions and surrounding bone morphology. Architecture surrounding 3 implant designs was compared to investigate whether osseous cuff formation is dependent upon implant shape and diameter.

The formation of a biological dimension has been documented using various implant designs and positions. In a series of publications using an animal model similar to the one presented in this study, Hermann et al demonstrated that bone contacts the implant where the smooth-rough interface is located, or apical to the microgap, if it exists, between the implant and abutment to imitate the biologic width occurring around teeth.[22,23] The hypothesis is that bacterial leakage at the microgap interface causes an inflammatory process which is isolated by the establishment of a soft tissue barrier. Other authors have challenged this concept, instead proposing that crestal mechanical stress is the cause of the observed remodeling.[24] Using rabbit tibiae, Duyck et al were able to analyze bone in the direction of applied forces. The present study, however, only investigated mesial and distal remodeling. It is possible that observation of the buccolingual dimension would have yielded further information, since nonaxial masticatory forces in this direction are significant. In addition, buccolingual crest width could affect peri-implant tissue maturation; the present study did not examine this variable.

Healing time after implant exposure must be sufficient to allow for tissue maturation. In the present study, radiographs were obtained during maturation (Fig 2) to ensure that cuff formation took place after implant exposure and not at the time of implant insertion. The 3-month maturation period is consistent with other studies.[22,25]

In a more recent report, Todescan et al reported on the placement of various 2-stage standard-size implants using an animal model.[26] The distance from the platform to the first bone-implant contact was assessed; additional bone loss was not detected if the implant was placed deeper in the bone. Thus, early remodeling did not necessarily cause bone resorption to the first thread, as previously suggested. The current results suggest that other parameters, such as implant diameter and shape, also influence bone remodeling.

Customized prosthetic restorations were not fabricated in the present study to obtain similar emergence profiles and forces on all implants. Although no occlusal contacts were present, some mechanical loading of the abutments occurred. It has been demonstrated that biological remodeling around implants with healing abutments is similar to that around restored implants.[13] However, it is possible that the presence of prosthetic contacts would have influenced the amount of force dissipated through the implants. In addition, the abutment or prosthetic emergence profile may also influence bone remodeling.[27,28]

In this study, healing abutments were placed at stage 2 and then briefly disconnected and reconnected every month for 3 months. Disconnection was carried out to imitate prosthetic impression making and abutment and crown insertion. It initiates further apical migration of gingival tissues.[25] However, immediate connection of healing abutments at stage 1 may have yielded similar results.[29]

Despite its clinical importance, few studies have considered the horizontal component of bone loss around implants as a critical parameter. Duyck et al studied the surface of the crater while comparing loading forces on an animal model.[24] Crater formation was only present when excessive transverse forces were applied, but this hypothesis is not supported by the results of the present study. Whether bone remodeling is caused by a biological or mechanical stress, the horizontal component is most likely variable, since it is in close proximity with the implant-abutment junction. The "cuff" may be constant between similar types of implants,[16] or it may vary between implant sizes or when coronal designs are modified.

Clinical studies using radiographs have also reported variations in bone crest remodeling width when comparing implant sizes or types.[30] Indeed, a wider cuff has been reported around wide-diameter implants.[31] Tarnow et al, in a human radiographic analysis, reported that this dimension is in the range of 1.3 to 1.4 mm.[11] This is consistent with the present histologic results on standard implants, where an average width of 1.9 mm was found histologically, since radiographic measurements may underestimate this dimension due to projections of buccal and lingual walls.

The present study suggests that there is a tendency of the horizontal distance to increase with a wider implant or a flared neck. This observation supports the hypothesis that platform diameter influences the cuff width. In addition, since a greater apical component of the cuff is also visible with wide or XP implants, the angle formed between bone and implant remains constant.

Although the apical position of bone-implant contact has been well documented, the present data clarify how implant diameter and design may influence adjoining osseous healing. The precise mechanism for such a difference remains unclear. Implant surgical site preparation would have likely caused bone remodeling prior to exposure. However, maturation after stage 2 was observed radiographically. In addition, a greater mechanical stress at the implant-abutment junction is unlikely, since forces in this study were similar on all implants. Greater fluid leakage could explain the differences observed. The design of the implant platform could affect the surrounding bone, regardless of forces or fluid penetration. In addition, a narrower prosthetic platform would likely influence remodeling outcome as well. Further, wider abutments or the presence of a prosthesis would have likely influenced force distribution, as suggested in photoelastic studies.[32] Finally, a combination of these factors is also possible. Although further human trials are necessary to validate the findings, the clinical implications of the present study are of importance: implant design may influence crestal bone remodeling, with implications for long-term maintenance and esthetic outcome.

ACKNOWLEDGMENTS

The authors would like to thank Dr Michael Rohrer and his team at the University of Minnesota for their outstanding processing of the histologic samples. They are also grateful to Biomet/3i for providing customized implants and instrumentation. This research was supported by a grant from the University of Michigan.

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